HIGH STRENGTH STEEL PRODUCT WITH IMPROVED FORMABILITY AND STEEL MANUFACTURING PROCESS

FIELD OF THE INVENTION

[0001] The present invention relates to high strength steel products, and more particularly to high strength low alloy (HSLA) flat rolled steel products having high yield strength and formability. The invention also relates to manufacturing processes for producing flat rolled steel products having high yield strength and formability.

BACKGROUND OF THE INVENTION

[0002] Most HSLA steels are produced in conventional processes where molten steel from a basic oxygen furnace (BOF) or an electric arc furnace (EAF) is cast, cooled, reheated and reduced in thickness while still hot in a rolling mill. The rolling mill reduces the thickness of the slab to produce thin gauge steel sheet or strip material having high strength characteristics. Some HSLA steels are produced by modern thin-slab or medium-slab casting processes in which slabs of steel, still hot from the caster, are transferred directly to a reheating or equalizing furnace prior to thickness reduction in the hot rolling mill.

[0003] HSLA steel products are commonly used for automotive and other applications where high strength and reduced weight are required. Such applications also require material having good formability to allow it to be shaped into parts.

[0004] Due to the steel microstructure and metallurgical transformations taking place in the material during hot rolling, reducing the gauge of the material also causes the material to become harder. As the hardness increases, further thickness reduction by rolling becomes more difficult, and the rolling mill must operate with increasing power levels to reduce the material thickness to the

desired level at a particular width. Due to the high power required to reduce the thickness, higher strength HSLA sheet or strip material, typically having a strength above about 350 MPa, is only available in limited widths.

[0005] As the strength of the material is increased through rolling, the subsequent formability of the material in service is reduced. This makes shaping of the material more difficult. Thus, rolling the HSLA material to light gauges interferes with the ability to shape the material, limiting its utility for many applications requiring high strength, light weight and good formability, such as automotive applications.

[0006] Therefore, there is a need for HSLA steel products having high strength, thin gauge and acceptable formability.

SUMMARY OF THE INVENTION

[0007] In one aspect, the present invention provides a process for producing a flat rolled steel product comprised of high strength, low alloy steel containing a hardness-promoting microalloy, the process comprising:

(a) casting molten steel to form a solid, as-cast steel product having a thickness, the as-cast product comprising austenite;

(b) charging the as-cast steel product into a furnace at a temperature above a recrystallization stop temperature of the austenite and above a precipitation temperature of the microalloy;

(c) transferring the as-cast product from the furnace to a first rolling apparatus;

(d) conducting a rough reduction step in the first rolling apparatus to reduce the thickness of the as-cast steel product by a first amount, thereby producing a rough-reduced steel product, wherein a temperature of the as-cast product entering the first rolling apparatus and a temperature of the rough-reduced

product exiting the first rolling apparatus are above the recrystallization stop temperature and above the precipitation temperature of the microalloy;

(e) holding the rough-reduced product at a temperature above the recrystallization stop temperature and above the precipitation temperature of the microalloy for a time sufficient to permit substantially complete recrystallization of the austenite and thereby reduce a grain size of the austenite;

(f) transferring the rough-reduced product to a second rolling apparatus;

(g) conducting a final reduction step in the second rolling apparatus to reduce the thickness of the rough-reduced product by a second amount, thereby producing a hot rolled steel product, wherein the second amount of thickness reduction is less than the first amount produced in the first rolling apparatus, and wherein a temperature of the rough-reduced product entering the second rolling apparatus and a temperature of the hot rolled product exiting the second rolling apparatus are above the precipitation temperature of the microalloy and wherein the temperature of the rough-reduced product entering the second rolling apparatus is above the recrystallization stop temperature; and

(h) cooling the hot rolled product to produce said flat rolled steel product, wherein the hot rolled product is cooled to a temperature which is less than the microalloy precipitation temperature and less than a temperature at which austenite transforms to ferrite.

[0008] In another aspect, the present invention provides an apparatus for producing a flat rolled steel sheet product of high strength, low alloy steel containing a hardness-promoting microalloy, the apparatus comprising:

(a) a casting apparatus in which molten steel is solidified to produce an as-cast steel product having a thickness, the as-cast product comprising austenite;

(b) a tunnel furnace in which the as-cast product is maintained at a temperature above a precipitation temperature of the microalloy and above a recrystallization stop temperature of the austenite;

(c) a rougher in which the thickness of the as-cast product is reduced by a first amount, thereby producing a rough-reduced product, the rougher being in sufficiently close proximity to the tunnel furnace that a temperature of the as-cast product entering the rougher is above the precipitation temperature of the microalloy and the recrystallization stop temperature;

(d) a heating apparatus for maintaining the rough-reduced product at a temperature above the precipitation temperature of the alloy and the recrystallization stop temperature;

(e) a strip mill comprising a plurality of rolling stands for reducing a thickness of the rough-reduced product by a second amount, thereby producing a hot rolled steel sheet product, wherein the strip mill is in sufficiently close proximity to the heating apparatus that a temperature of the rough-reduced product entering the strip mill is above the precipitation temperature of the microalloy and the recrystallization stop temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

[00010] Figure 1 is a schematic diagram illustrating the process and apparatus according to the invention;

[00011] Figure 2 is a graph of yield strength against thickness of HSLA steel produced according to the present invention; and

[00012] Figure 3 is a graph of n-value (formability) against thickness of HSLA steel produced according to the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[00013] The process according to the present invention preferably utilizes many of the same process steps and apparatus as modern thin slab and medium slab processes for producing flat rolled steel products. Typical processes of this type utilize a furnace to produce molten steel, at least a portion of which may comprise scrap material. The molten steel is cast, preferably on a continuous basis, to produce a slab having a thickness of from about 30 to about 200 mm. According to the present invention, It is preferred that the hot as-cast slab is directly charged into a reheating or equalizing furnace to prevent excessive cooling. However, the process of the invention is also compatible with processes in which the as-cast slab is allowed to cool before further processing.

[00014] A preferred process and apparatus according to the present invention are schematically illustrated in Figure 1. As in known thin slab and medium slab casting processes, molten steel 10 is produced in a furnace (not shown) which may preferably comprise a BOF or an EAF. The molten steel 10 is withdrawn from the furnace and is transferred to a ladle 12, also known as a ladle metallurgy station (LMS), where alloy elements may be added to the molten steel 10. The molten steel 10 is transferred from the ladle 12 to a tundish 14. The tundish 14 has a nozzle 16 through which the molten steel 10 flows into a water-cooled mold 20 which preferably comprises a continuous casting mold. The steel solidifies in the mold 20 to form an as-cast steel product 22 which, as shown in Figure 1, preferably comprises a continuous sheet or strip of steel which is shaped and guided along a path by rollers 24.

[00015] In most known thin slab and medium slab casting processes, the thickness of the as-cast product is from about 30 to about 200 mm, typically in the range of from about 30 to 80 mm, and more typically from 50 to 75 mm. Even more typically, the thickness of the as-cast product is no greater than 50 mm so

that the as-cast material can be directly accepted by a hot rolling strip mill. In the process of the present invention, the thickness of the as-cast product is preferably in the range from about 70 mm to about 80 mm, more preferably about 70 mm to about 75 mm, and even more preferably about 72 mm.

[00016] In terms of composition, the steel preferably comprises a high strength low alloy (HSLA) steel composition which includes a hardness-promoting microalloy. Preferably, the microalloy is a vanadium nitride alloy having a composition which is the same as or similar to the V-N steel compositions set out in Table 1 of Glodowski, "Vanadium Microalloying in Steel Sheet, Strip and Plate Products", pages 145 to 157, Use of Vanadium in Steel, A Selection of Papers Presented at the Vanitec International Symposium, Beijing, China, 13-14 October, 2001, published by Vanitec, Vanadium International Technical Committee, Westerham, Kent, England, 2002, preferably those having a yield strength of about 550 MPa or greater. The Glodowski paper is incorporated herein by reference in its entirety.

[00017] Most preferably, the nitrogen is present in a sub-stoichiometric amount relative to the vanadium (i.e. mole ratio of V:N >1:1; weight percent ratio V:N > 3.6:1). In addition to vanadium and nitrogen, the steel composition may also contain one or more other elements selected from the group comprising carbon, manganese, silicon, molybdenum, niobium, and aluminum. In a particularly preferred embodiment of the invention, the steel composition according to the invention comprises up to about 0.080 wt% carbon, from about 1.00 to about 1.65 wt% manganese, from about 0.01 to about 0.40 wt% silicon, from about 0.07 to about 0.13 wt% vanadium, from about 0.015 to about 0.025 wt% nitrogen and about 0.008 wt% molybdenum or niobium. In an example of a composition having an acceptable V:N ratio, the nitrogen content is about 0.020 wt% and the vanadium content is about 0.10 to about 0.12 wt%.

[00018] In terms of microstructure, the as-cast steel product 22 is comprised of a mixed austenite structure comprised of grains having a wide range of grain sizes, ranging roughly from about 100 μm to about 1,000 μm. The austenite grains in the surface regions of the as-cast product 22 tend to be larger columnar grains while those in the interior of the as-cast product tend to be smaller particles with a more spherical shape. The grains of the as-cast product are subjected to refinement as described below in order to provide a fine grain structure throughout the product and to attenuate variations in grain size and structure, thereby contributing to the high strength and formability of the final product.

[00019] As mentioned above, in conventional processes the as-cast slab is cast, cooled and reheated prior to entering the strip mill. In order to minimize use of energy to reheat the slab, the as-cast steel product in the process of the invention is preferably not permitted to cool to ambient temperature after emerging from the continuous casting mould 20. Preferably, the as-cast product is directly charged into an equalization or reheating furnace 25 which causes retention of the coarse as-cast microstructure. The temperature inside the equalizing furnace 25 is from about 1050 to about 1200°C, this temperature being high enough to prevent precipitation of VN particles in the steel, and to permit recrystallization of austenite in subsequent process steps. It will, however, be appreciated that the process according to the invention includes embodiments in which the as-cast slab is cast, cooled and reheated as in conventional processes.

[00020] In known thin-slab and medium-slab casting processes, the as-cast product is transferred from the equalization furnace directly to a hot rolling strip mill in which the product is reduced to its final thickness dimension. In a typical process, the strip mill may reduce the thickness of the steel product from about 50 mm to below 1.5 mm. The strip mill typically comprises about five or six rolling

stands which are closely coupled together, with a typical interpass time of from about 0.3 to 6 seconds.

[00021] In contrast, according to the present invention, the as-cast product 22 is transferred directly from the equalization furnace 25 to a rougher 26, also referred to herein as a roughing mill. In the rougher 26, the thickness of the as-cast product 22 is reduced, preferably in one pass, by an amount of from about 40 to about 60% of the thickness of the as-cast product, thereby producing a rough-reduced product 28. For example, where the thickness of the as-cast product is 75 mm, the rougher reduces the thickness of the product to the range of about 30 to 45 mm. The rougher 26 is preferably in close proximity to the equalization furnace 25, so that the as-cast product 22 is not significantly cooled prior to entering the rougher 26. Accordingly, the rougher entry temperature is preferably in the range of about 1050°C to 1200°C.

[00022] During the roughing operation, the columnar and mixed grains in the as-cast austenite structure are flattened and elongated. Deformation of the austenite grains under selected temperature conditions and for selected periods of time, as in the present invention, causes recrystallization of the austenite and results in reduction of austenite grain size as well as attenuation of variations in the grain size and shape.

[00023] Thus, the temperature at which the as-cast steel product 22 enters the rougher 26 (the "rougher entry temperature") and the temperature at which the rough-reduced steel product 28 exits the rougher 26 (the "rougher exit temperature") must be sufficiently high to permit recrystallization of the austenite to occur. Most preferably, the rougher entry temperature and the rougher exit temperature are greater than the recrystallization stop temperature so as to promote recrystallization of the austenite. Also, the rougher entry temperature and

the rougher exit temperature are sufficiently high to prevent precipitation of the microalloy during the roughing stage.

[00024] In addition to proper temperature control during the roughing stage, the inventors have found that it is important to carefully control the temperature of the rough-reduced product 28 after it exits the rougher 26. Specifically, the rough-reduced material 28 is preferably held at a temperature high enough and for a time sufficient to permit substantially complete recrystallization of the austenite grains, preferably such that at least about 90 percent of the austenite grains are within about 100 to about 400 μm in size. The recrystallized austenite grains tend to be round and have an attenuated variation in structure as compared to the as-cast product.

[00025] Preferably, the rough-reduced product 28 is held at a temperature greater than the crystallization stop temperature of the austenite, and even more preferably is held at a temperature in the range from about 1020°C to about 1150°C. Preferably, the rough-reduced product 28 is held at this temperature for a time of from about 10 to about 30 seconds. During this time, the relatively coarse austenite grains of mixed shape and size, which have been flattened and elongated in the rougher 26, recrystallize to the smaller, more regular grain size and shape mentioned above.

[00026] In order to ensure that the temperature of the rough-reduced product 28 is maintained at a suitable level during recrystallization, the rough-reduced product 28 preferably exits the rougher 26 and is transferred directly to a heating apparatus such as a second furnace (not shown) or a heated run-off table 30 having a temperature sufficient to maintain the temperature of the rough-reduced product 28 in the range of about 1020°C to about 1150°C mentioned above.

[00027] After the recrystalization step, the rough-reduced product 28 is transferred to a second rolling apparatus, preferably a hot rolling strip mill 32, for reduction to its final thickness. Preferably, the strip mill 32 is in close proximity to the heated run-off table 30 so that the temperature of the rough-reduced product 28 entering the strip mill 32 is substantially the same as the temperature at which the austenite was recrystallized. In other words, the temperature of the rough-reduced product 28 entering strip mill 32 is preferably greater than the recrystallization stop temperature and is greater than a temperature at which significant precipitation of microalloy will occur. Furthermore, the temperature of the rough-reduced material 28 is sufficiently high so that the temperature of the hot rolled product 46 exiting the rolling mill is greater than a temperature at which austenite is transformed to ferrite and is greater than a temperature at which significant precipitation of the microalloy will occur in the rolling mill. Preferably, the temperature of the hot rolled product 46 exiting the rolling mill is in the range of from about 820°C to about 950°C. Therefore, the rough-reduced product 28 remains in the austenitic state during the entire rolling operation and the microalloy essentially remains in solution during the entire rolling operation. Furthermore, the rough-reduced product 28 entering the strip mill 32 is at a temperature sufficient for further recrystallization to occur as it passes through the strip mill, resulting in further grain refinement.

[00028] The strip mill 32 itself is of conventional form, comprising a plurality of rolling stands in which the thickness of the rough-reduced product is progressively reduced to produce the hot rolled product 46 having a thickness of from about 1 mm to about 6 mm, usually from about 1 mm to about 2 mm. Preferably, the strip mill 32 comprises from four to six stands, and the preferred strip mill schematically shown in the drawings comprises a total of five stands 34, 36, 38, 40 and 42. The time interval between adjacent rolling stands, also referred to as the “interpass time” is preferably from about 0.3 to about 6 seconds.

[00029] After hot rolling the product to its final thickness in the strip mill, the hot rolled product is quickly cooled, preferably at a rate up to about 70°C/s by water as shown at 48, to a temperature at which austenite is transformed to ferrite, and at which the microalloying elements precipitate. After cooling to an appropriate temperature, the flat rolled product 50 may preferably be wound into a coil 52 for shipment to the end user. The coiling temperature is preferably in the range of from about 550°C to about 700°C. The.cooled (ambient temperature) product is referred to herein as the flat rolled steel product 50.

[00030] In most known thin-slab and medium-slab casting processes, the steel entering the strip mill retains the columnar and mixed grain structure of the as-cast slab. Much of the recrystallization of the austenite in the prior art processes occurs between the first and second rolling stands in the strip mill. However, due to the relatively short interpass times in the strip mill, this amount of time is insufficient to permit complete recrystallization of the austenite. Thus, the austenitic grain structure of the product remains in a relatively variable state and does not achieve the same level of refinement produced in the process of the present invention. As the product is rolled it becomes stronger, making further thickness reduction difficult. On known thin-slab and medium-slab processes which do not utilize a rougher, the entire thickness reduction from the as-cast product to the final product must be accomplished in the strip mill. As the gauge is reduced, the power required to achieve the final dimensions increases and as the mill works harder, it becomes more difficult to keep tolerances within acceptable limits.

[00031] In the process of the present invention, the added recrystallization step provides the rough-reduced steel product with increased grain refinement over the as-cast product. It is known that grain refinement is a major strengthening mechanism and therefore the flat rolled steel product 50 has high

strength, typically exceeding 70ksi and preferably having a strength of at least about 550 MPa (80ksi). In this regard, Figure 2 graphically illustrates a plot of yield strength against thickness (gauge), which shows that flat rolled steel product produced according to the invention has high yield strength, in excess of 80 ksi, regardless of the gauge to which it is reduced. However, since there is little or no precipitation of the microalloy until after the material passes through the strip mill, the material being rolled is relatively "soft" as compared to known processes. Therefore, less power is required to roll the material to its final dimensions and there is a corresponding improvement in dimensional control. Since power required by the rolling mill is a function of volume and cross-sectional area of the material being rolled, the reduced power demands of the process according to the invention also permits the production of material having greater width dimensions than previously possible.

[00032] The inventors have also found that the flat rolled steel product 50 according to the invention possesses greater formability than materials produced by prior art thin-slab and medium-slab casting processes. As mentioned above, formability is important in the production of shaped parts. Formability is represented by an "n-value" determined in accordance with ASTM A646 (00), Tensile Strain Hardening Exponents (n-value) of Metallic Sheet Material, a longitudinal tensile test. The inventors have surprisingly found that the formability of the flat rolled steel product 50 is essentially independent of the final thickness to which the product is rolled. This is shown graphically in Figure 3, which comprises a plot of the n-value against thickness of the product. The n-values achieved according to the method of the invention are preferably above about 0.1, more preferably in the range from about 0.1 to about 0.15. Even more preferably, the n-values are about 0.13. Thus, the formability of the steel is preserved independently of the level of thickness reduction in the strip mill, permitting the production of formable high strength steel in a wide range of gauges.

[00033] Although the invention has been described in connection with certain preferred embodiments, it is not restricted thereto. Rather, the invention includes within its scope all embodiments which fall within the scope of the following claims.